Nuclear Nonproliferation:
A Perspective on Recent Thinking

Alan Waltar & Ron Omberg

Pacific Northwest National Laboratory

PHYSOR-2004

Chicago, Illinois

April 27, 2004

Setting the Stage: 1930s

- Some Physicists Argued that Nuclear Energy Could Only be Used as a Weapon
- Others Said No—It Could Only be Used as a Power Source
- They Were Both Partially Right….

1940s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 1945 U.S. becomes 1st Nuclear State

Policy of Secrecy and Denial

- 1949 U.S.S.R. becomes 2nd Nuclear State

1950s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 1952 U.K. becomes 3rd Nuclear State
- 1953 President Eisenhower's Atoms for Peace Initiative
- 1957 IAEA Founded

1960s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 1960 France becomes 4th Nuclear State
- 1964 China becomes 5th Nuclear State
- 1968 NPT (Non-Proliferation Treaty) Formulated

1970s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 1970 NPT Ratified (IAEA Safeguards)
- **1974 India becomes 6th Nuclear State**
- 1976 President Ford changes policy with PDD
- 1977 Carter administration opposes reprocessing
- 1978 Nuclear Non-Proliferation Act (NNPA)
  - Tightened export controls
  - Constrained subsequent arrangements

  } U.S. disputes with W. Europe & Japan on reprocessing & MOX

- 1978-1981 INFCE found no "silver bullet"

1980s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 1981 Reagan administration does not oppose civil reprocessing and breeder reactor development in countries where proliferation does not present a problem
- 1983 "Programmatic Consent" for reprocessing U.S. origin fuel awarded to Sweden and Norway
- 1987 "Programmatic Consent" for reprocessing U.S. origin fuel awarded to Japan

1990s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 1994 National Academy of Sciences definition of Spent Fuel Standard
- 1994 Evidence of a DPRK Weapons Program
- 1995 ANS Seaborg Commission on Management of Sensitive Materials
- 1995 "Programmatic Consent" for reprocessing U.S. origin fuel awarded to EURATOM
- 1998 Pakistan Becomes 7th Nuclear State

2000s

1940s	1950s	1960s	1970s	1980s	1990s	2000s

- 2001 9/11 accentuates new terrorism thrust
- 2002 DPRK threatens to withdraw from NPT
- 2003 Iran situation
- 2004 Libyan situation
  - » Additional DPRK Threats
  - » Pakistan Black Market Revelations

Time to Revisit Eisenhower's Atoms for Peace Challenge?

- **How can the world benefit from peaceful nuclear energy…**

while

- **Minimizing the risk of nuclear proliferation?**

Present Challenge

Review alternative forms of Series One fuel containing mixtures of plutonium, neptunium, and possibly other constituents in order to assess their nonproliferation characteristics

↓

Can the current U.S. fuel cycle be closed, consistent with non-proliferation objectives?

Study Group

	Expertise
• Pascal Baron (CEA)	Reprocessing
• Christine Brown (BNFL)	Fuels
• Takehiko Mukaiyama (JAIF)	Physics
• Massimo Salvatores (CEA)	Core Design
• Bruce Kaiser (WGI)	Fabrication
• Bruce Matthews (LANL)	Safeguards
• Lee Peddicord (A&M)	Fuels
• Ron Omberg (PNNL)	Fuel Cycle
• Alan Waltar (PNNL)	Chairman

Alternative Fuel Cycles Reviewed

- **Classical PUREX/MOX**
  - European and Japanese approach
  - Dominated by national commercial enterprises
  - Employs large scale plants
  - Relies on IAEA safeguards
  - Continual safeguards improvements

- **UREX with minor actinide separation**
  - Advanced U.S. approach
  - Primarily intended to relieve load on geologic repository
  - Currently at lab scale
  - Capable of incorporating advanced safeguards technologies
  - Inclusion of Np with the Pu (possibly even in initial fuel load)

Fuel Cycles Reviewed (Continued)

- **DUPIC**
  - Republic of Korea approach
  - Heavy reliance on intrinsic proliferation resistance
  - Uniquely suited of ROK situation
  - In initial stages of development
- **Inert Matrix Fuel** (non-fertile fuel)
  - Specifically designed to burn plutonium
  - Intended for LWR
  - Requires some fuel development
  - Also has some implications for reactor safety
  - Particularly suited to Swiss situation

Observations

- No silver nonproliferation bullet
- Fuel cycles are unique to national situations
- All fuel cycles incorporate proliferation resistance, but do so by different means
- Once-Through cycle uses the Spent Fuel Standard as its nonproliferation basis
- No fuel cycle is bereft of proliferation resistance:
  - Some steps or stages in each fuel cycle have more and some have less

Historical Nonproliferation Thinking

- The Once-Through has long been considered the *sine qua non* of proliferation resistance

- This was reaffirmed in:
  - Nonproliferation Systems Assessment Program
  - International Nuclear Fuel Cycle Evaluation
  - Weapons Plutonium Disposition

- But maybe the time has come to improve the sophistication of the thinking

Types of Proliferation Resistance

Intrinsic

A property of the system that cannot be altered without very substantial efforts

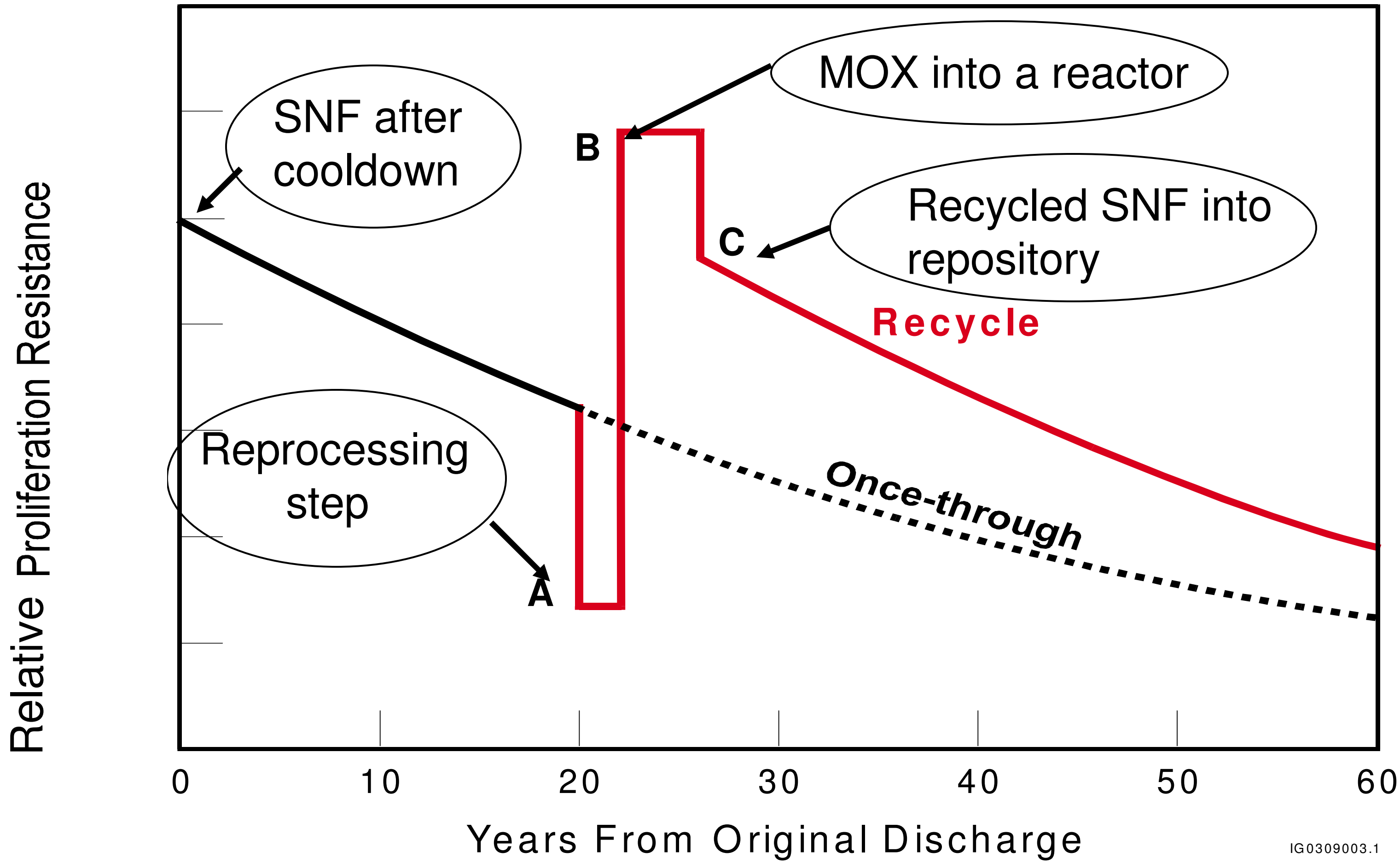
e.g. isotopic composition, radiation barrier

Extrinsic

Institutional or engineering systems designed to reduce system vulnerability

e.g. Guns, Guards, and Gates

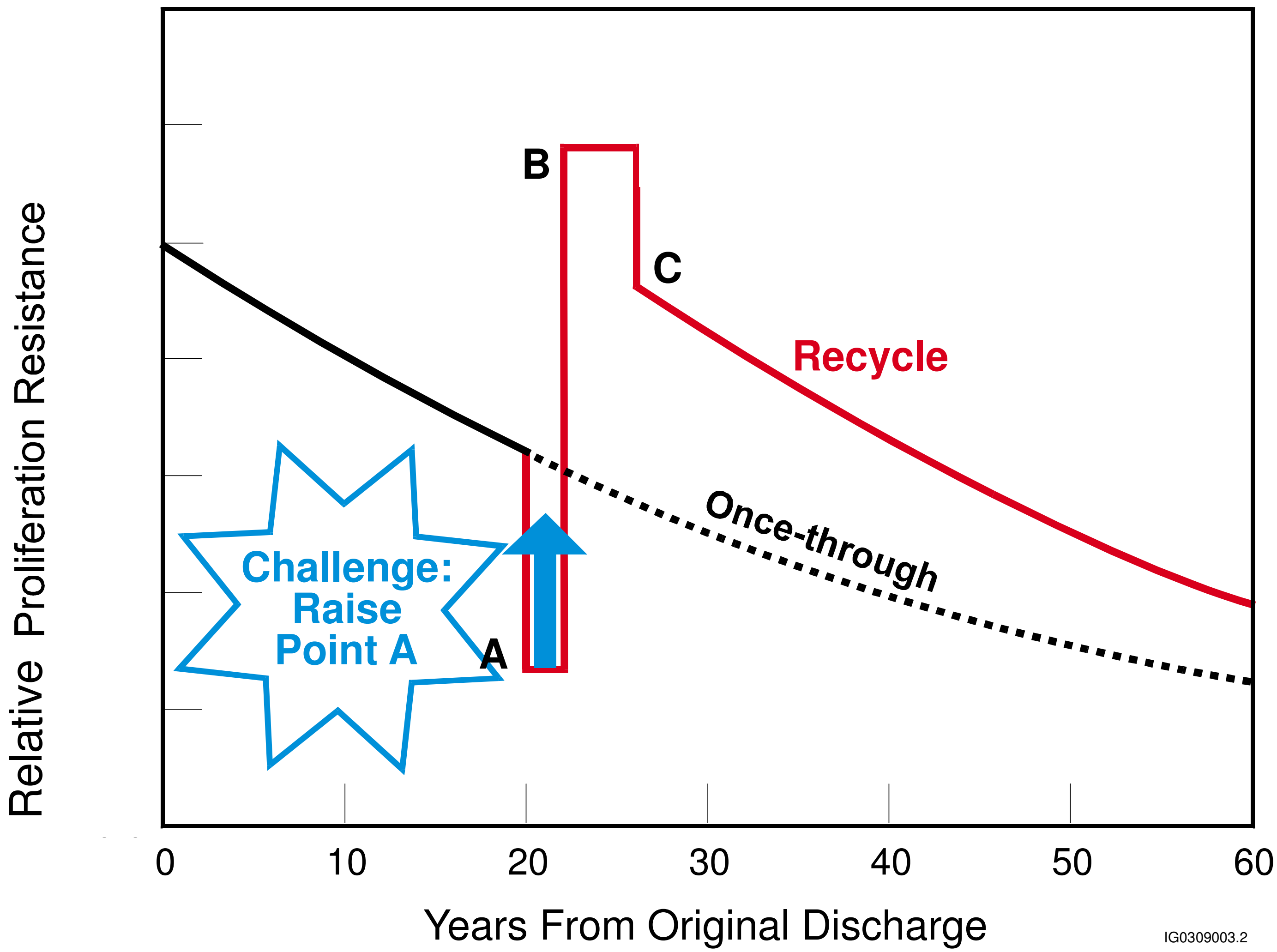
General Intrinsic Resistance of a Fuel Assembly



Key Fuel Cycle Transition Points

- Point A:
  - Intrinsic Proliferation Resistance is reduced during reprocessing and re-fabrication
  - Duration is limited in time
  - Extent of proliferation resistance drop depends upon safeguards incorporated into plant and process
- Point B:
  - Intrinsic Proliferation Resistance is increased with fuel in reactor
- Point C:
  - Intrinsic Proliferation Resistance drops without reactor protection
  - Intrinsic Resistance substantial with radiation barrier re-established

General Intrinsic Proliferation Resistance of a Fuel Assembly



Implications

Recognize Point A as Time of "Vulnerability"
Will always exist in full recycling campaign

Focus Advanced Safeguards (Extrinsic Measures) on Point A
(examples noted below):

- **Evolutionary improvements from present systems (UK, France)**
  - Material balance zones
  - Methods of measuring concentrations
- **Improvements from New Japanese Rokkosho Plant**
  - Smaller material balance zones
  - Advanced measuring techniques
- **New technologies (UREX Early Design Improvements)**
  - Improved on-line mass spec measurements
  - Improved on-line β & γ measurements
  - Improved detection of Pu/Np diversion
    - Np daughter is gamma emitter Pa-233
    - Diversion pathway must allow Pa-233 gamma to go undetected
  - Smaller material volumes
    - e.g. Centrifugal contactors

Potential Opportunities at Point A

- Separate uranium and send fission products and minor actinides to repository
    - Reduces repository volume, but not heat load
    - Likely reduces repository storage costs
- Separate uranium, separate and store fission products, and send minor actinides to repository
    - Repository could support more reactors
        - (some controversy here)
- Separate uranium, separate and store minor actinides (plus Tc and I), and send fission products to repository
    - Minor actinide storage can meet spent fuel standard for ~ 50 years
        - Eu-154 has sufficiently strong gamma
    - Repository lifetime becomes significantly enhanced

Representative Proliferation Resistant Values
using
Multi-Attribute Analysis
(Prof. Bill Charlton, Texas A&M)

Attributes	Intrinsic	Extrinsic
DOE Attractiveness Level	X	
Heating Rate for Pu	X	
Weight Fraction of Even Pu Isotopes	X	
Radiation Dose Rate	X	
Concentration	X	
Size/Weight		X
Frequency of Measurement		X
Measurement Uncertainty		X
Separability		X
% Steps That Use Item Accounting		X
Probability of Unidentified Movement		X
Physical Barriers		X
Inventory		X
Fuel Load Type		X

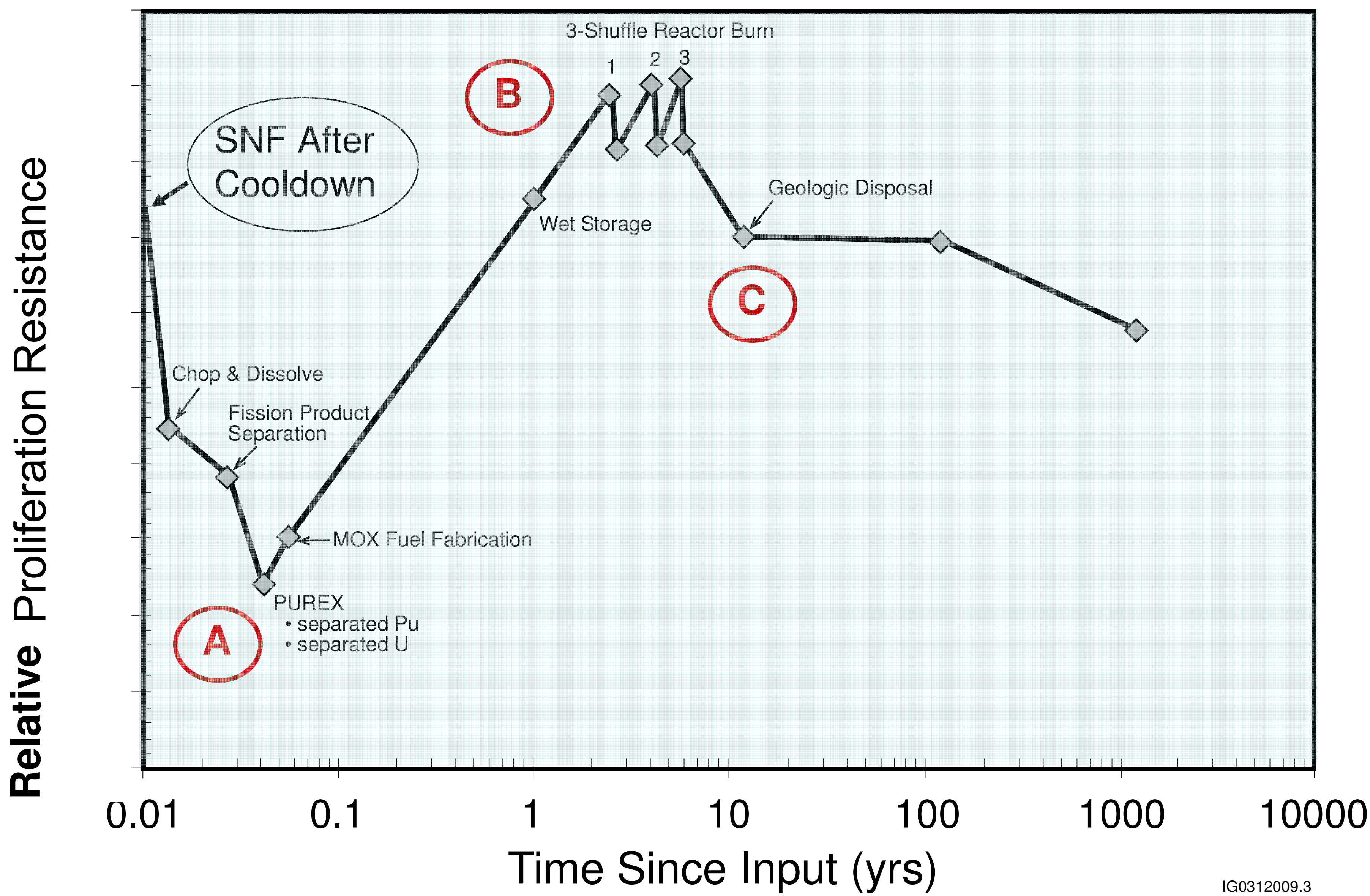


Figure 4: Proliferation Resistance as a function of time for the PUREX/MOX process

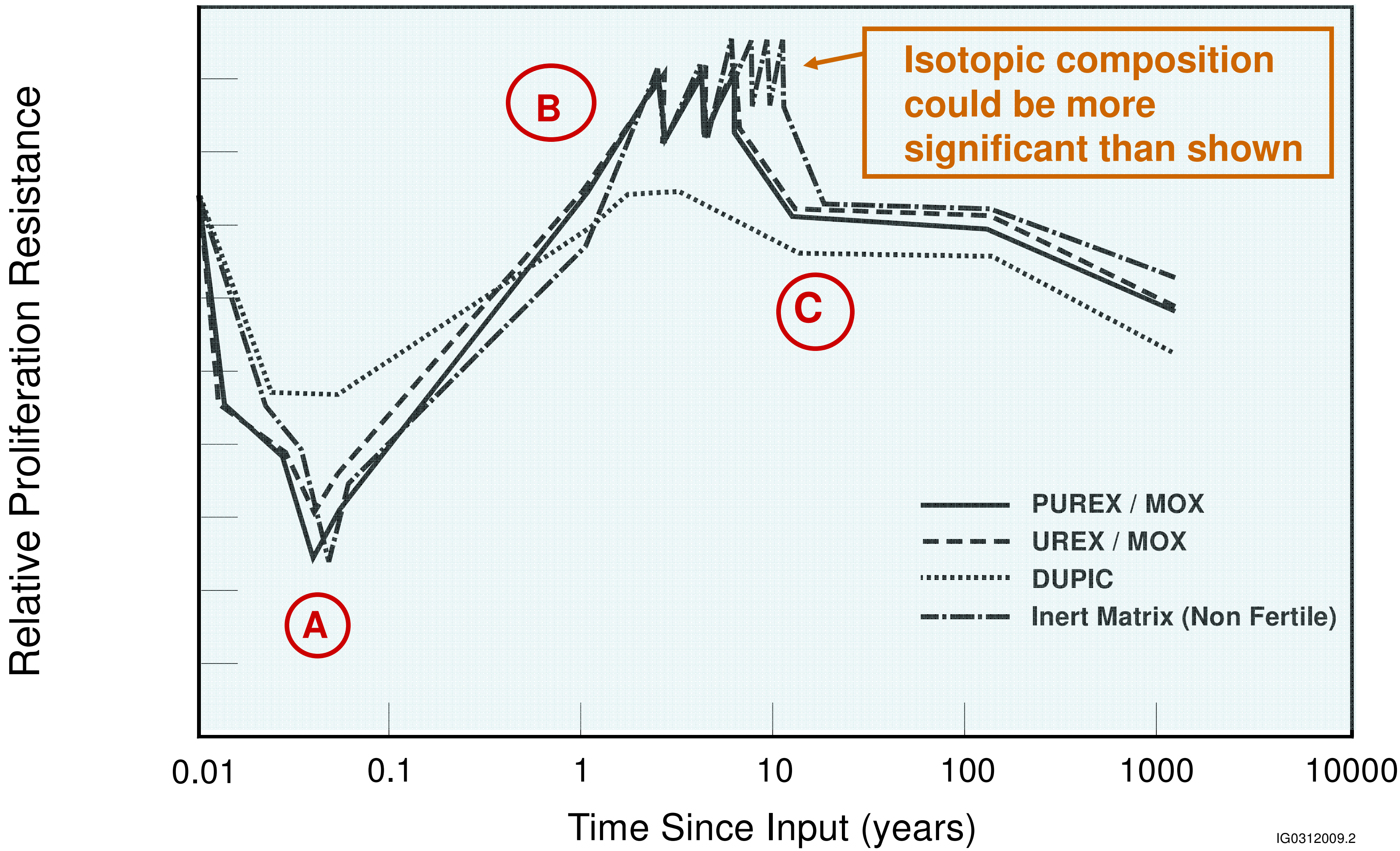
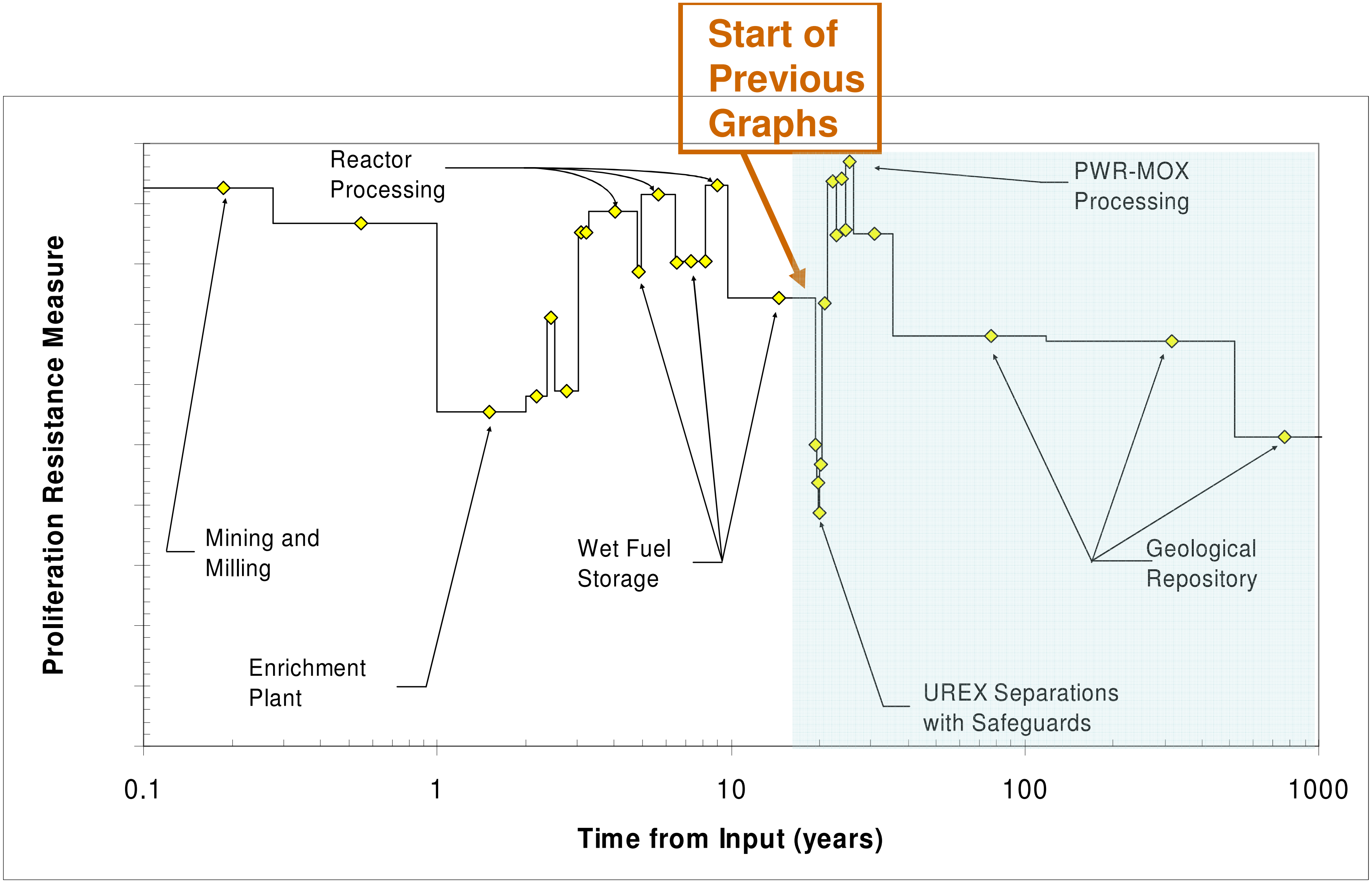


Figure 6: Comparison of Proliferation Resistance for Four Fuel Cycles

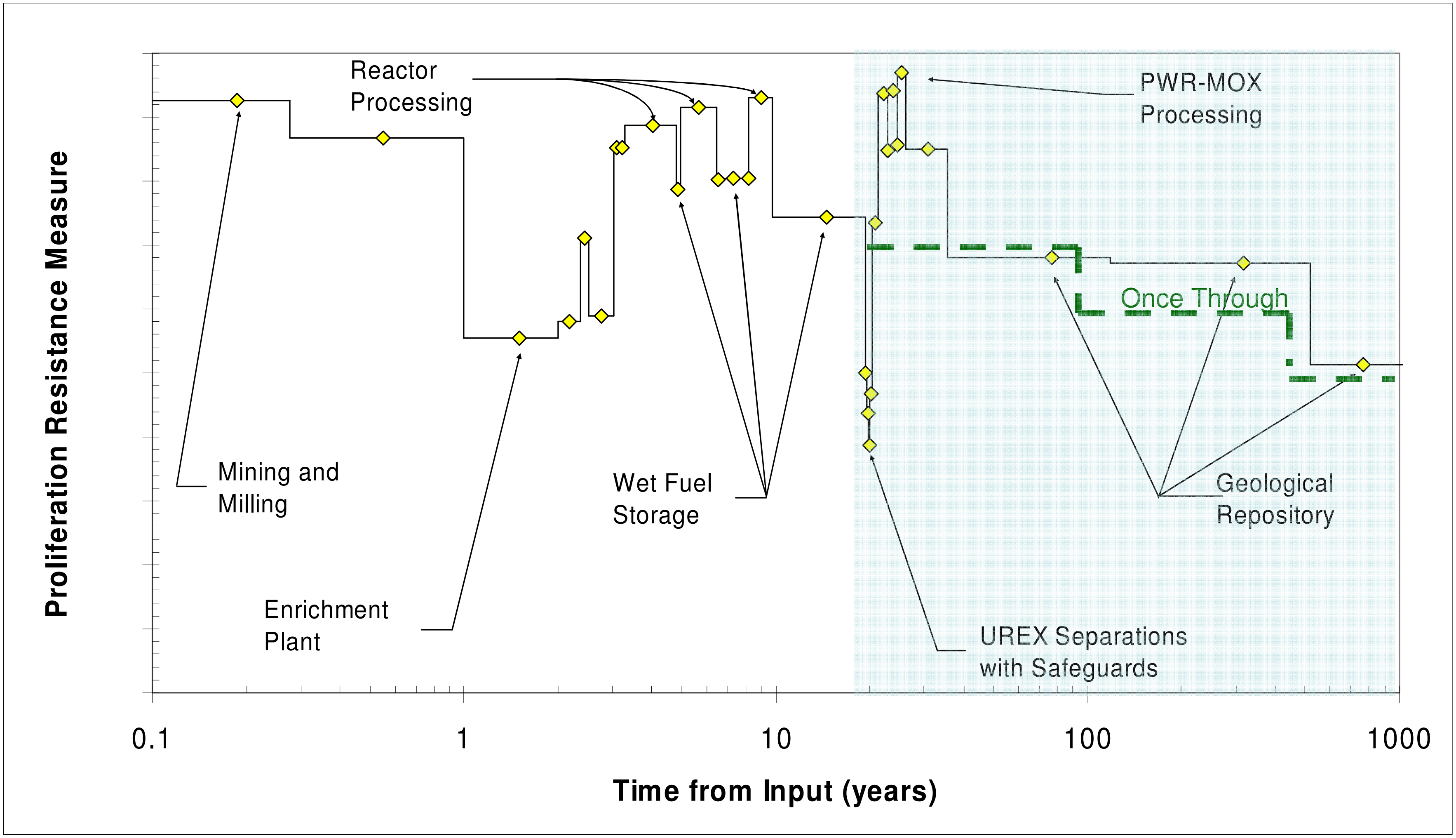
Now Consider

FULL FUEL CYCLE

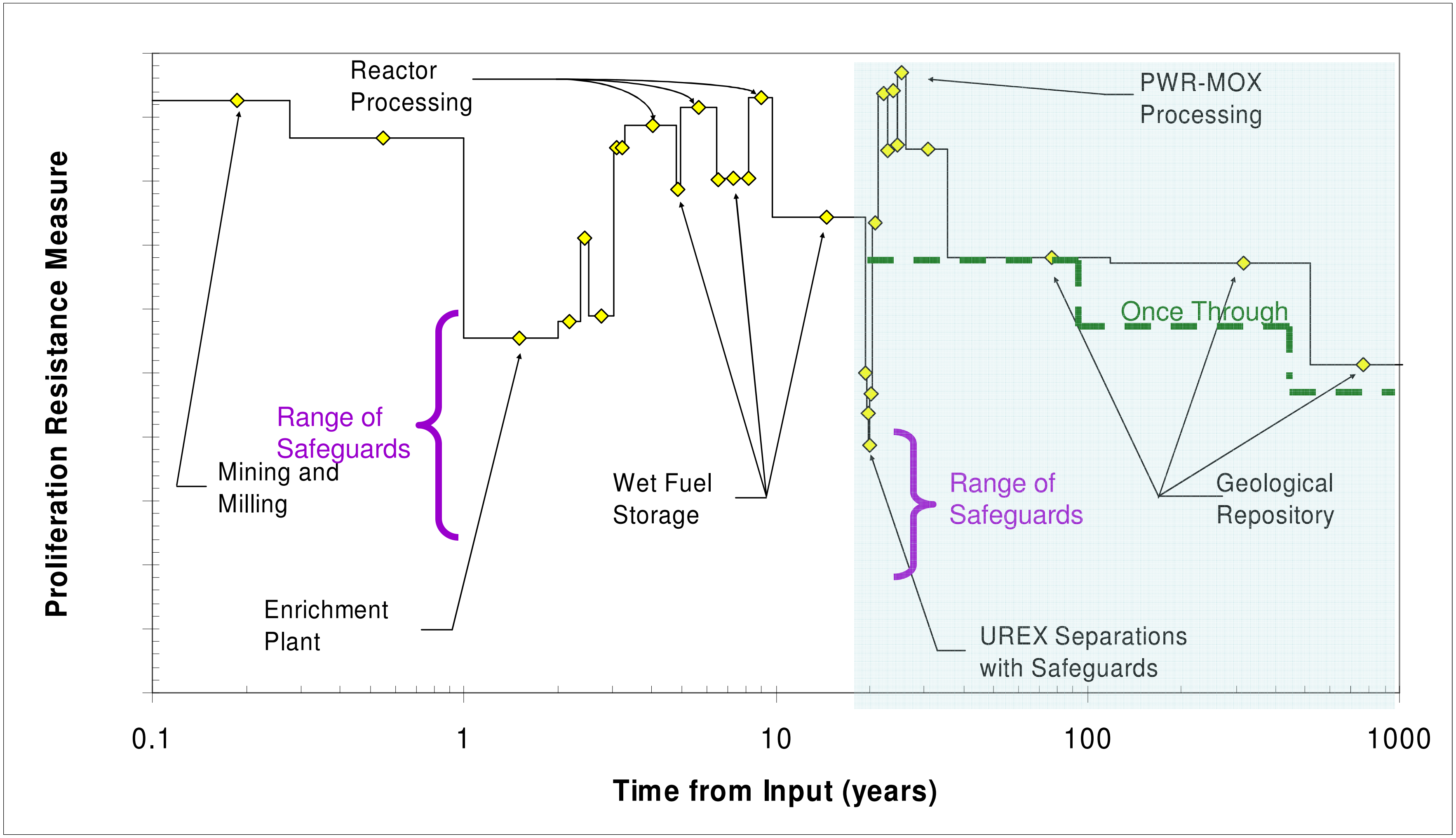
(Mine to Repository)



Full Fuel Cycle



Once-Through Overlay



Potential Safeguard Ranges

(Enrichment and Reprocessing)

Preliminary Observations

- Proliferation resistance is time dependent
- Re-establishing radiation barrier may be more effective than allowing continued decay
  - Integrated proliferation resistance of Closed Fuel cycle may be greater than for Open Fuel cycle
- **Reprocessing window of vulnerability exists but is known and limited**
- **Advanced safeguards technologies essential to minimize vulnerability**
- **Enrichment step also needs consideration**
- Minor actinides can be stored consistent with spent fuel standard

Some Current Thinking

Significant proliferation resistance can be obtained by:

Incorporating nonproliferation characteristics as a formal part of the design process

- Requiring that Functions and Requirements (F&R) specifically address nonproliferation issues
- Minimizing vulnerability at Point A
- Reviewing designs against nonproliferation F&R:
  - Just as is done for for safety

Expected Outcome

- **Use of designer ingenuity to maximize nonproliferation attributes**
- **Will clarify tradeoff between nonproliferation improvements and additional cost**
- **Will produce:**
  - Process flow sheets with nonproliferation attributes
  - Small material balance zones
  - Real time accountability
  - Innovations in nonproliferation equipment design
  - Other as yet undefined designer innovations

Use Designer Ingenuity to Identify Low-Cost Nonproliferation Improvements

		Proliferation Resistance	
		Low	High
Cost	Low	**Consider and Decide on a Case by Case Basis**	**Do Immediately**
	High	**Probably Don't Do But Decide on a Case by Case Basis**	**Consider and Possibly Do**

A Parallel PR&PP Approach

(Proliferation Resistance & Physical Protection)

- **The PR&PP approach** is focused on:
  - **Developing a methodology for comparing nonproliferation characteristics of plants and systems that is:**
    - Quantitative and standardized
    - Historically related to the PRA approach, at least in some sense
  - **Begins with a threat definition**
  - **Identifies potential diversion pathways**
  - **Can use metrics to characterize ease or difficultly of pathways**

Complementary Approaches

- **PR&PP approach** is:
  - More analytical
  - Capable of producing objective independent evaluations
  - Based upon proven historical success of the PRA approach

- **Present approach** is:
  - More design oriented
  - Emphases designers intuition and innovation
  - Requires that the design be reviewed against nonproliferation attributes as part of the design process
  - Uses metrics to evaluate vulnerable areas to improve the design
  - Will produce systems that score better against the PR&PP approach

An Alternate Paradigm

- Employ **Partitioning in Policy**...in addition to partitioning in physics

- **Fuel Cycle States** and **Reactor States**
  - Fuel Cycle States: Impeccable Non-Proliferation Credentials
  - Reactor States: Less than Impeccable Non-Proliferation Credentials

Items to Ponder

- **Advantages**
  - Reactor States spared from huge fuel cycle expenses
  - Much tighter solution to non-proliferation concerns
- **Challenges**
  - New diplomatic efforts required
  - Development of the nuclear battery

Conclusions

- New thinking may be required for Nuclear Energy to reach full potential
- Proliferation resistance is time dependant
- New technology may sufficiently alleviate points of vulnerability
- Partitioning by Credentials a long-term possibility